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AutoMan 2.0

DECISION SUPPORT SOFTWARE FOR AUTOMATED MANUFACTURING INVESTMENTS

USER MANUAL

Developed by:
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In cooperation with:
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PREFACE

AutoMan is a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. It was developed at the Center for Computing and Applied Mathematics of the National Institute of Standards and Technology (NIST). The project was conducted in collaboration with the NIST Automated Manufacturing Research Facility, the United States Navy, and Computer Aided Manufacturing--International (CAM-I), a consortium of manufacturing firms.

The authors wish to thank all those who contributed excellent ideas and suggestions incorporated into AutoMan. Christoph J. Witzgall of NIST verified some of the mathematical algorithms for computing weights and ratings from pairwise comparison judgments. The comments of NIST reviewers Belinda L. Collins, Sieglinde K. Fuller, Harold E. Marshall, and Rosalie T. Ruegg inspired many useful improvements to the documentation and software. Volunteer beta testers from corporations, universities, professional associations, and the CAM-I Cost Management System program suggested other significant enhancements and revisions. The authors are particularly indebted to Robert Bennett of the Accountancy Department of Northern Illinois University and Steven Neises of Woodward Governor for their very careful review and testing of AutoMan and their extensive written and oral suggestions for making the product more useful to practicing managers, accountants, and engineers.

Disclaimer: Certain trade names and company products are referenced to illustrate procedures. In no case do these references imply recommendation or endorsement by the National Institute of Standards and Technology, nor do they imply that the products are necessarily the best available for the purpose.

ABSTRACT

This manual documents AutoMan, a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. The program permits users to combine quantitative and qualitative criteria in evaluating investment alternatives. Quantitative criteria could include such traditional financial measures as Life-Cycle Cost and Net Present Value as well as such engineering performance measures as throughput and setup time. Qualitative criteria could include flexibility and product quality. First, the user specifies the evaluation criteria and the investment alternatives to be evaluated. Second, the user makes pairwise comparisons between criteria to establish their weights. Third, the user rates each investment alternative with respect to the criteria. The pairwise comparison process helps the user rate the qualitative criteria, while measured performance data, such as cost, setup time, or throughput, can be entered for quantitative criteria. AutoMan combines ratings with criteria weights into an overall rating for each investment alternative and then ranks alternatives. Finally, graphical sensitivity analysis can be conducted to visualize the overall ratings of every alternative for every possible weight that could be assigned to any criterion. AutoMan comes with sample decision models and a manual that includes a detailed tutorial, a glossary of evaluation criteria, a bibliography, and an index.

Key Words: Analytic hierarchy process; automation; automated manufacturing; decision support software; economic evaluation; microcomputer software; multi-criteria decisions; performance measures; qualitative data; sensitivity analysis.

HOW TO INSTALL AND START AUTOMAN 2.0

AutoMan 2.0 runs on an MS-DOStm microcomputer with at least 640 kilobytes of RAM and a floppy diskette drive. The new sensitivity analysis feature requires a graphical monitor and adapter card with one of the following resolutions: Herculestm (720x348), CGA (640x200), EGA (640x350), or VGA (640x480). Printing a Sensitivity Analysis graphic requires a graphical printer (i.e., a laser or dot matrix but not a daisy wheel printer). AutoMan may be run directly from a 360 kilobyte floppy drive or it may be first installed on a hard drive and then run from there.

Users of the original version of AutoMan should note that the procedure for installing AutoMan 2.0 on a hard drive will upgrade your software while preserving all your data files.

To run from a floppy drive:

Insert the distribution diskette into a floppy drive that is write-compatible with the distribution diskette (e.g., drive A), type **A:** and press **↵** to go to the A drive. To run the program, type **AUTOMAN** and press **↵**, or **AUTOMAN M** for Monographic systems like the Compaqtm Portable II or III. To run AutoMan from a high density 1.2 megabyte floppy drive, you must first copy all the files from the distribution diskette to a write-compatible high density diskette. If you have a hard drive, AutoMan will run much faster if you install it on the hard drive.

To install on a hard drive:

Insert the diskette into any floppy drive (e.g., drive A), type **A:** and press **↵** to go to the A drive. Then type **INSTALL** to install AutoMan on the C drive. Press **↵** and the installation will begin. All of the AutoMan program and data files will be automatically copied to a directory called **\AUTOMAN** on the C drive. To install AutoMan on a drive other than C, specify the drive letter (e.g., type **INSTALL D** to install AutoMan on drive D).

To run from a hard drive:

Go to the directory in which AutoMan is installed by typing **CD\AUTOMAN** and pressing **↵**. Then type **AUTOMAN** and press **↵**, or **AUTOMAN M** for Monographic systems like the Compaqtm Portable II or III.

The AutoMan 2.0 distribution diskette contains these files:

- AUTOMAN.EXE Executable program.
- MODELIST.DBF Data file of model names.
- *.DBF - Several data files containing sample models.
- PRINT.SET - Parameter file for your graphical printer.
- PRX_TBL.BIN - File of printer driver data for most printers.
- *.@ - Two font files for graphical sensitivity analysis.
- INSTALL.BAT - Batch file to install AutoMan on a hard disk.

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1. INTRODUCTION

Most capital investment decisions are made using such traditional measures of financial worth as net present value, life-cycle cost, and return on investment. These measures incorporate the stream of costs and benefits of an investment over time into a single measure. The measures are either denominated in dollars or derived from dollar-denominated data. Financial worth measures are often applied to reduce costs such as labor, materials, inventory, and rework. They tend to focus more on cost reduction than revenue creation because the former is usually easier to quantify.

Measures of financial worth are often inadequate to evaluate investments in automated manufacturing. The shortcomings of relying solely on these measures when evaluating automated manufacturing investments are discussed throughout the literature.¹ The most pervasive complaint is that measures of financial worth fail to account fully for the nonfinancial impacts of these investments. Nonfinancial impacts may be either quantitative or qualitative. Nonfinancial quantitative impacts can be measured, but not easily converted to dollars. They may consist of non-monetary measures of performance such as throughput, cycle time, and schedule attainment. Qualitative impacts cannot be measured at all. They typically involve issues that affect the long-term or strategic position of the firm, such as technology advancement, plant modernization, product quality, flexibility, competitive position, and even the survival of the firm.

Although industrial managers recognize the need for analytical techniques that account for nonfinancial impacts, there has been little change in the way most automated manufacturing investment decisions are made. Indeed, in a 1984 survey of the National Electrical Manufacturers Association, 91 percent of business executives reported using traditional measures of financial worth as the major criteria for automation investment decisions (Sullivan, 1986, pp. 42-50).

Approaches that include more than one measure of performance in the evaluation process are multi-attribute or multi-criteria decision methods.² The advantage of these methods is that they can account for both financial and nonfinancial impacts. The Analytic Hierarchy Process (AHP) is one multi-criteria decision method that has recently gained in popularity and been applied to a wide variety of complex decision problems. The AHP technique was developed in the 1970's by Thomas L. Saaty at the Wharton School of the University of Pennsylvania.³

The AHP structures a complex decision into a hierarchy of its elements. It then establishes shares of influence, or relative weights, among the elements through a sequential process of pairwise comparisons. Pairwise comparisons are based on judgments about relative differences between comparable elements. The relative weights are combined to derive a single overall rating for each decision alternative.

¹For example, see Fred Choobineh, "Justification of Flexible Manufacturing Systems," in Choobineh (1986, pp. 269-281), Computer Aided Manufacturing-International, Inc. (1988), Jelinek (1986), Sullivan (1986), and Canada and Sullivan (1989).

²For more information on multi-criteria decision methods, see Zeleny (1982), Goicoechea *et al.* (1982), and Canada and Sullivan (1989).

³For information on the AHP, see Saaty (1988) and Gass (1985).

One of the major strengths of the AHP is that it permits inconsistencies among the pairwise comparison judgments. For example, A need not be four times as important as C just because A is twice as important as B and B is twice as important as C. In technical terms, this means that the user is not forced to preserve cardinal transitivity among comparisons. The AHP even provides an explicit measure of inconsistency that indicates how far the pairwise judgments deviate from perfect cardinal transitivity.

Several shortcomings of the AHP are discussed in the literature. The major criticisms question the lack of a theoretical framework for modeling decision problems into a hierarchy (Zahedi, 1986, p. 102), the use of subjective judgments in making pairwise comparisons (Reeve, 1988, pp. 26-27), the use of the eigenvector method for estimating relative weights (Zahedi, 1986, p. 103), and the lack of a formal treatment of risk (Harker, 1988).

Despite its limitations, the AHP appears ideally suited for economic decisions on automated manufacturing investments. It incorporates into a unified analytic framework a wide variety of normally incommensurable impact criteria, some of which may be financial, some nonfinancial yet quantifiable, and some qualitative. It appeals to decision makers because they directly participate in the process and can generally understand how results are produced. Furthermore, it has the advantage of dealing formally with inconsistency in human judgments. Some researchers have already begun applying the AHP to automated manufacturing investment decisions.¹

This manual describes the microcomputer program AutoMan, a special-purpose adaptation and modification of the AHP designed to support investment decisions about automated manufacturing equipment. AutoMan is useful for selecting the best investment in automated manufacturing equipment and for ranking a set of investment alternatives. AutoMan requires that the investment alternatives be identified and well specified beforehand. If financial worth measures are to be factors in the decision, AutoMan requires that these measures have been separately estimated. Similarly, actual performance data or qualitative judgments must be available on the merits of each alternative with respect to nonfinancial evaluation criteria to be used in the decision.

AutoMan evaluates up to seven investment alternatives simultaneously. If there are more than seven alternatives, you can evaluate them in groups of seven, and then reevaluate those that rank high in each group against one another. The outcome of this procedure, however, is sensitive to the way alternatives are initially grouped. AutoMan evaluates either (1) mutually exclusive alternatives (i.e., select only one) or (2) non-mutually exclusive alternatives (i.e., select more than one) as long as the alternatives are independent of each other (i.e., their impacts are not affected by acceptance of other alternatives).

AutoMan may be used to arrive at a team decision requiring input from senior managers, accountants, financial analysts, and engineers. Senior managers could structure the decision into a hierarchy of its elements and establish priorities among the elements; accountants and financial analysts could develop financial data for the investment alternatives; and engineers could provide the nonfinancial data and judgments on the performance of alternatives.

Although AutoMan is designed for selecting investments in automated manufacturing equipment, it is applicable to a wide variety of decision problems. AutoMan is appropriate for supporting any multi-criteria decision involving both quantitative and qualitative evaluation criteria.

¹For examples, see Arbel and Seidmann (1984), Varney *et al.* (1985), Sullivan (1986), Wabalickis (1988), Canada and Sullivan (1989), and Troxler and Blank (1989).

2. OVERVIEW OF AUTOMAN

The overview of AutoMan summarizes the general procedures and guiding principles to follow when building and applying decision models. The details and mechanics of using the program are illustrated in the Tutorial that follows in Section 3.

Using AutoMan to support a decision regarding automated manufacturing investment alternatives involves four steps. First, identify evaluation criteria, group them into logical categories, and name the investment alternatives for evaluation. Second, make pairwise comparisons to establish the relative importance of categories as well as of evaluation criteria within each category. Third, rate alternatives with respect to each criterion. For measurable criteria, use actual performance data for rating. For qualitative criteria, use the pairwise comparison method. Fourth, let AutoMan combine the ratings for each investment alternative with the criteria weights and rank alternatives by their overall ratings.

2.1 Build a Model

In the first step you select an existing decision model or build a new one. The model structure is a three-tier hierarchy consisting of a topmost tier of "categories," a middle tier of "criteria," and a bottom tier of investment "alternatives." A new model is built by identifying the evaluation criteria to be considered in the decision, grouping similar criteria into categories, and labeling the investment alternatives to be evaluated.

The evaluation criteria comprising the middle tier are the expected impacts of the investment alternatives, both quantitative and qualitative. All significant impacts should be fully reflected in the choice of evaluation criteria. The criteria should be selected and defined to avoid ambiguity and redundancy.

Similar evaluation criteria are grouped into categories, defining the topmost tier of the model. The three basic types of impacts discussed in Section 1 -- financial, nonfinancial quantitative, and qualitative -- are helpful in grouping evaluation criteria into categories.

Models will not necessarily group criteria into categories exactly matching the three basic types of impacts. For example, one model may group cost-related financial criteria in one category, benefit-related financial criteria in another, nonfinancial quantitative criteria in a third, and qualitative criteria in a fourth. Combining different types of criteria (e.g., financial and qualitative) in a single category is not recommended because of the potential difficulty in comparing the criteria. Keep in mind, however, that AutoMan lets you create any grouping. The only limits are no more than seven categories of evaluation criteria with up to seven criteria per category, for a total of 49 criteria.

In building models, the evaluation criteria within each category must be reasonably comparable -- no criterion should be more than ten times as important as any other criterion in that category. If a criterion is more than ten times as important as another, it should be reclassified into another category or redefined and decomposed into several criteria. On the other hand, if a criterion is less than one tenth as important as any other, it probably is not significant enough to warrant inclusion in the analysis. Similarly, the categories themselves must be reasonably comparable.

Once the categories and criteria have been developed, the investment alternatives are identified. The investment alternatives should be sufficiently specified so that you can at least make reasonable judgments as to relative performance with respect to all the criteria. Further, since retaining the existing manufacturing system may possibly be preferred to all new investment alternatives, the existing system should be included in the list of investment alternatives. The alternatives may be either mutually exclusive (i.e., select only one) or non-mutually exclusive alternatives (i.e., select more than one) as long as the alternatives are independent of each other. Seven alternatives may be evaluated simultaneously. For more than seven alternatives, evaluate them in groups of seven, and then re-evaluate those that rank high in each group against one another. The initial grouping, however, may influence the outcome of this procedure.

Building the decision model is one of the most important and difficult steps in AutoMan. To help you get started, the program offers three sample models, any one of which may be used as a template from which to develop a more suitable model. These models are provided only to illustrate different structures; such generic models are unlikely to articulate a particular organization's goals and strategies. All the sample models contain categories and criteria but only the model EXAMPLE contains data on weights or ratings. The data in EXAMPLE are by definition purely hypothetical because weights and ratings need to be specific to a particular decision-making environment.

To further help you build models, the Glossary in the back of the manual defines those criteria for evaluating automated manufacturing investments that are used in the sample models of AutoMan. Refer to the Glossary for criteria to consider when building a new model and revise and add to the definitions to meet the needs of your organization.

2.2 Weight Categories and Criteria

The second step derives weights for categories and then for the individual criteria in each category. The weights are critical because they establish the relative importance of each criterion to the overall decision. The importance of each criterion to the overall decision depends on its "share," which is the product of the criterion weight and the weight for the category to which the criterion belongs. The criteria shares all sum to unity. In general, the more criteria in a model, the less important is each criterion to the overall decision.

The weights are based on your judgments about the relative importance of criteria when compared in a pairwise fashion. If there are n elements (categories in the model or criteria within a category) to be weighted, then there are only $n(n-1)/2$ pairwise comparisons to be made. Thus, 4 evaluation criteria require 6 ($= 4 \times 3 / 2$) comparisons. This is because of two assumptions: (1) each criterion is of equal importance to itself; and (2) if A is twice as important as B, then B is half as important as A. The procedure for comparing criteria is the same as that for comparing categories. When all the pairwise comparisons are entered, AutoMan derives a system of weights that sum to unity by computing the normalized eigenvector of the largest eigenvalue of the matrix of pairwise comparison values.¹ This approach establishes the relative importance of categories as well as criteria within each category.

¹AutoMan computes the normalized eigenvector by raising the matrix of pairwise comparisons to powers that are successively squared each time. This is the computational method suggested by Saaty (1988, p. 179).

In addition to the weights, AutoMan reports an Inconsistency Ratio. As indicated in Section 1, the pairwise comparison method lets you reveal their inconsistencies of judgment. Perfect consistency results when A is always judged to be four times as important as C if A is twice as important as B and B is twice as important as C. The Inconsistency Ratio measures how far all the pairwise judgments deviate from perfect consistency among all comparisons. If the Inconsistency Ratio exceeds 0.10, it is advisable to redo the pairwise comparisons. Otherwise, the overall ratings may be distorted. The Tutorial illustrates a convenient method to force any comparison value to be perfectly consistent. The best way to improve consistency, however, is to make better informed comparisons based on more information gathered either through research or expert judgment of others.

2.3 Rate Alternatives

The third step in AutoMan is to rate each investment alternative with respect to every criterion in the model. There are two rating methods: pairwise comparison and direct entry of performance data. The pairwise comparison method is the same as that used in Step 2 for establishing the relative importance of criteria. The only difference is that, rather than being asked to compare the importance of criteria, you are asked to compare the desirability of investment alternatives with respect to each criterion. The pairwise comparison method must be used for rating if there are no reliable performance data on the alternatives for the criterion.

The performance data method requires actual data on the performance of each alternative with respect to the criterion. The data must be either **directly** or **inversely** proportional to the desirability of each alternative. For example, revenue is directly proportional if \$200 of revenue is considered twice as desirable as \$100 of revenue. Scrap costs are inversely proportional if \$200 of cost is considered half as desirable (twice as bad) as \$100 of cost. Negative and zero values have no meaning and are ignored in deriving ratings since performance data must be proportional to desirability. The units in which the data are entered do not matter as long as the same units are used for each alternative within the criterion being evaluated by the performance data method.

Once the performance data are entered, AutoMan computes a set of ratings for the alternatives that sum to unity. For directly proportional data, the rating for each alternative is the ratio of its performance data value to the sum of the performance data values for all alternatives. For inversely proportional data, the rating is the ratio of the inverse of the alternative's performance data value to the sum of the inverses of the data values for all alternatives. This approach establishes the relative desirability of the alternatives with respect to each criterion.

2.4 Compute Overall Ratings

The final step in the process is carried out by AutoMan. All weights developed for the criteria are combined with ratings to compute a single, weighted-average rating for each alternative. The overall ratings are displayed, and all alternatives are ranked by them. The alternative with the highest overall rating is the best choice taking into account the relative importance of each criterion established by the user in Step 2 as well as the relative desirability of the alternatives with respect to each criterion in Step 3.

If the decision involves non-mutually exclusive alternatives (i.e., more than one may be selected), then the ranking by overall rating can be used to select the top set of alternatives. If there are more than seven alternatives to evaluate, then a copy of the model may be made

to cover the other alternatives. The user may then redefine the set of investment alternatives and keep the same categories and criteria. The new copy of the model will start out with the same pairwise comparison data and resulting weights as the original model. The new model will have a new set of alternatives which will require new ratings to be established for the alternatives with respect to each criterion. Provided the alternatives are grouped so that the better ones are not all clustered into the same model, the overall ratings could be used to establish an approximate ranking of all the alternatives.

2.5 Conduct Sensitivity Analysis

The sensitivity analysis feature requires a graphical monitor and adapter card with one of the following resolutions: Hercules (720x348), CGA (640x200), EGA (640x350), or VGA (640x480). Press **C** from the AutoMan Menu to select Compute Overall Ratings and then **S** to select the Sensitivity Analysis option. Then move the light bar to the criterion on which you want to conduct sensitivity analysis and select it by pressing **↵**. A graphic screen will appear displaying the results of the sensitivity analysis.

The sensitivity analysis screen plots a set of straight lines, each representing one of the alternatives being evaluated in your decision model. The horizontal axis gives the percentage share of importance (weight) of the criterion being analyzed. The vertical axis gives the Overall Ratings of the alternatives. For reference, the current percentage share is marked with a vertical line. In this one graph you can see the Overall Ratings of every alternative for every possible percentage share assigned to the criterion of interest. The points where the lines intersect the left axis (the share is zero) indicate how alternatives would be rated if this criterion were totally ignored and all weight formerly attributed to it were redistributed proportionately to the remaining criteria. The points where the lines intersect the right axis (the share is 100 percent) indicate how alternatives would be rated if this were the only criterion that mattered and all other criteria were ignored. Breakeven points occur where the plots of two alternatives intersect. The rankings of the two alternatives reverse when the criterion share moves from one side of a breakeven point to the other.

Printing a Sensitivity Analysis graphic requires a graphical printer (laser or dot matrix, but not a daisy wheel). When you first try to print a graphic, you are asked to select a printer and to set several printer parameters. Scroll through the list of printer definitions available to highlight the proper one and select it by pressing **↵**. If your printer is not listed, try an Epsontm for a dot matrix or a Hewlett Packardtm for a laser. Then set the size and margins of the printed graph. The default orientation of the printed graph is Portrait (i.e., with the graph title parallel to the **short** edge of the paper). Answer **N** to select Landscape orientation (i.e., title parallel to the **long** edge of the paper). Finally, set whether the printer will force a form feed to eject the paper after printing. You can later change these settings by pressing **P** for Printer Setup from the Sensitivity Analysis Screen. You can change the printer by pressing **F2** from the Printer Setup screen. If the graphical printing does not work on your printer, try running the utility program, GRAPHICS.COM, which comes with most versions of DOS before starting AutoMan. Then press Shift-PrtScr to screen dump the image displayed on the screen.

3. TUTORIAL

The Tutorial shows how to use AutoMan to evaluate alternative investments in automated manufacturing equipment. The four major steps outlined in Section 2 are illustrated in detail.

The instructions throughout the Tutorial and at the bottom of each screen in the program use a common set of symbols to represent keystrokes that perform specific actions. The symbols, keystrokes, and resulting actions are as follows:

<u>Symbol</u>	<u>Keystroke</u>	<u>Resulting Action</u>
↵	Enter key	Enter data or redo comparisons
← →	Right and left arrow keys	Move within an element
↑ ↓	Up and down arrow keys	Move between elements
Del	Delete key	Delete a character or delete a model
Ctrl-Y	Hold down the Control key and press Y	Delete an element
Ctrl-Home	Hold down the Control key and press Home	View the criteria or view the ratings
Ctrl-End	Hold down the Control key and press End	View Inconsistency Ratios and shares
Esc	Escape key	Cancel current action or retreat to previous level

To start AutoMan:

- Type **CD\AUTOMAN** and press ↵.
- Type **AUTOMAN** and press ↵.
- When the opening screen appears, press ↵.

The AutoMan Menu appears with four options corresponding to four steps required to evaluate alternative investments (Exhibit 1).

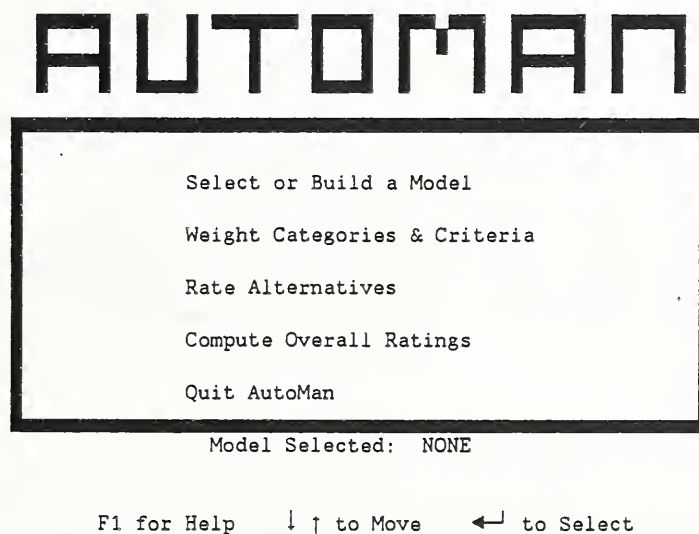


Exhibit 1. AutoMan Menu.

Press **F1** at the AutoMan Menu for a summary of the four major steps or modules (Exhibit 2). Throughout AutoMan press **F1** to see help screens that explain the current procedures.

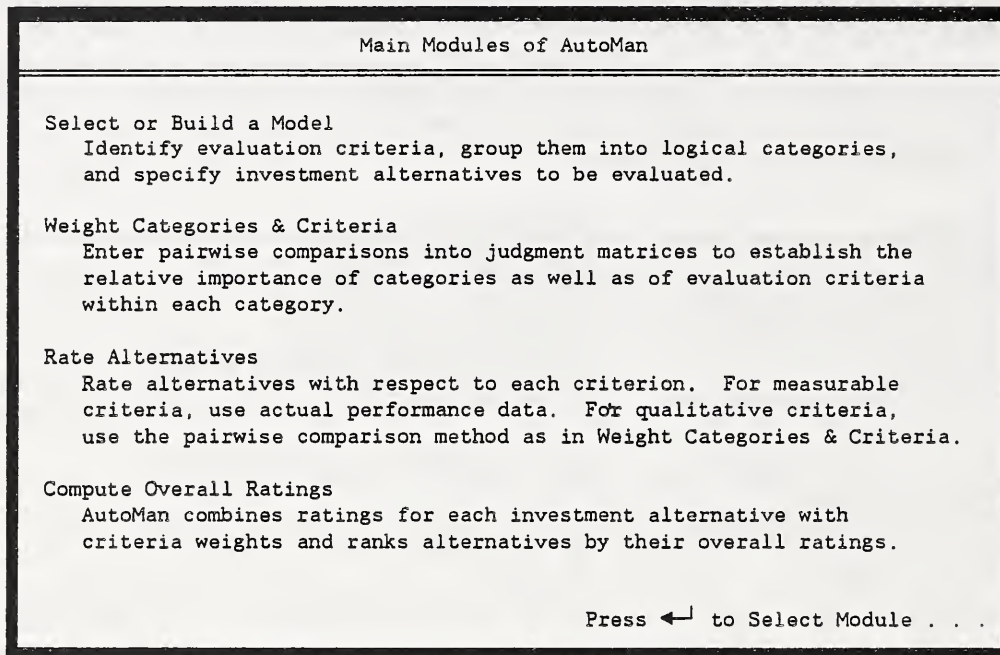


Exhibit 2. Help Screen Explaining the AutoMan Menu.

3.1 Select or Build a Model

There are two ways to make a selection from the AutoMan Menu:

- Move the highlighted bar to the desired option and press **<**; or
- Type the initial letter of the option.

To choose Select or Build a Model:

- Press **<** (since the first option is already highlighted).

This option displays a list of sample models included with AutoMan, along with a brief description, the date created, and the number of evaluation criteria in each (Exhibit 3). The two top models, **SMALL** and **LARGE**, are sample models to illustrate the general pattern by which models may be structured. They contain no data on the weights or ratings. The third sample model, **EXAMPLE**, has both a structure and hypothetical data on the weights and ratings. Press the **F1** key for a brief description of the options listed at the bottom of the screen.

To view the structure of any model:

- Move the highlighted bar to the model.
- Press **F3**.
- Press **Esc** to return to the Model Selection and Building screen.

The **EXAMPLE** model has the same structure as the model you are about to build, but all the data have already been entered. If you do not want to practice building a model and entering data in the Tutorial, you may select **EXAMPLE** and go directly to Section 3.2, Weight Categories and Criteria, and review each step in the process with a complete set of data already entered. To select **EXAMPLE**, use **↓** to highlight it and press **<**.

Model Selection and Building			
Model Selected: NONE			
NAME	DESCRIPTOR	DATE	CRITERIA
SMALL	Two Categories	03/25/91	5
LARGE	Four Categories	03/25/91	16
EXAMPLE	Practice Model with TUTORIAL Data	03/25/91	9
Use ↓ ↑ to highlight Model and press: F1 for Help Esc to Exit ← to Select F3 to Edit F4 to Build F5 to Copy Del to Delete			

Exhibit 3. List of the Decision Models.

To build a new model:

- Press the **F4** key at the Model Selection and Building screen. AutoMan then asks for three entries at the bottom of the screen (Exhibit 4).
- A new model will be built from scratch so you do not want to pattern the model after the template model. Hold the **Ctrl** key down and press **Y** to delete everything to the right of the cursor, erasing the default name of the template model.
(If you do not erase the name of the template model, then the categories, criteria, and alternatives of the template model will appear on the screen for building the new model. You may then add, delete, or edit any of these model elements.)
- Press ←.
- Type the new model name, **TUTORIAL**.
- Type its descriptor, **Practice Model**, and press ←.

Model Selection and Building			
Model Selected: NONE			
NAME	DESCRIPTOR	DATE	CRITERIA
SMALL	Two Categories	03/25/91	5
LARGE	Four Categories	03/25/91	16
EXAMPLE	Practice Model with TUTORIAL Data	03/25/91	9
Template Model: SMALL New Model: Esc to Cancel Descriptor:			

Exhibit 4. Building a Model: Enter Name and Descriptor.

To enter these category labels:

- (Be sure to enter all categories in succession from left to right; any categories entered beyond a blank entry will be ignored.)

Exhibit 5. Building a Model: Enter Categories.

Enter the Monetary criteria:

- 10 -

Enter Performance Measures criteria:

- Type **CycleTim**, **Schedule**, **Thruput**, and **Yield**, the abbreviated forms of the criteria labels.
- Press ← four times.

Building a New Model		
Model: TUTORIAL		
Enter at least 1 and no more than 7 Categories of Evaluation Criteria:		
Monetary	PerfMeas	Strategc
Enter up to 7 Evaluation Criteria for each Category:		
1. InitCost	CycleTim	Flexity
2. Revenue	Schedule	Quality
3.	Thruput	Risk
4.	Yield	
5.		
6.		
7.		
Enter at least 2 and no more than 7 ALTERNATIVES to be evaluated:		
Existing	New	
F1 for Help ↓ ↑ for Next/Prior Label PgDn to Save Esc to Cancel		

Exhibit 6. Building a Model: Enter Criteria and Alternatives.

The last category is abbreviated Strategc and is meant to include the evaluation criteria often associated with a company's strategic plan. For the model TUTORIAL, this category consists of three evaluation criteria: Flexibility, Quality, and Risk.

Enter the Strategic criteria:

- Type **Flexity**, **Quality**, and **Risk**, the abbreviated forms of the criteria labels.
- Press ← five times.

Once the criteria for all categories have been entered, you must enter at least two and up to seven investment alternatives. These alternatives will be evaluated with respect to each criterion entered above. The TUTORIAL model has two investment alternatives: Existing and New (Exhibit 6). Existing is the current system, and New represents a specific level of investment in automated manufacturing equipment.

Enter the alternatives:

- Type **Existing** and **New**.
- Press **PgDn**.

Exhibit 7 displays the revised list of decision models now in the system. Note that TUTORIAL, the model you just built, has been added at the bottom of this list, indicating that the TUTORIAL model has been saved. Since TUTORIAL is the model currently selected it is shown at the top of the screen.

Model Selection and Building Model Selected: TUTORIAL			
NAME	DESCRIPTOR	DATE	CRITERIA
SMALL	Two Categories	03/25/91	5
LARGE	Four Categories	03/25/91	16
EXAMPLE	Practice Model with TUTORIAL Data	03/25/91	9
TUTORIAL	Practice Model	03/28/91	9
Use ↓ ↑ to highlight Model and press: F1 for Help Esc to Exit ← to Select F3 to Edit F4 to Build F5 to Copy Del to Delete			

Exhibit 7. New List of Decision Models Including TUTORIAL.

To view the model structure (Exhibit 8):

- Highlight the TUTORIAL model.
- Press **F3**.
- Press **Esc** to return to the Model Selection and Building screen.

Edit Labels of Hierarchical Structure Model: TUTORIAL	
Descriptor: Practice Model	
Categories of Evaluation Criteria Monetary PerfMeas Strategc	
Evaluation Criteria InitCost CycleTim Flexity Revenue Schedule Quality Thruput Risk Yield	
Alternatives to be Evaluated Existing New	
F1 for Help ↓ ↑ for Next/Prior Label PgDn to Save Esc to Cancel	

Exhibit 8. Structure of the TUTORIAL Model.

Now you could modify the model. By pressing F3 to edit, you could change any of the labels for categories, criteria, and alternatives, but not the structure of the model. By pressing F5 to copy, you could enter a new set of alternatives but keep the structure the same. By pressing F4 to build, you could completely modify the structure by changing the number of criteria, categories, and alternatives. With F4 the data on weights and ratings from the original model are no longer relevant to the new structure and so are not transferred to the new model. Now press **←** to select the TUTORIAL model and return to the AutoMan Menu.

3.2 Weight Categories and Criteria

At the AutoMan Menu, type **W** to select Weight Categories and Criteria.

Press the **F1** key to display a screen of instructions describing how to weight categories. Categories are weighted by using a scale of 0.100 to 9.900 to indicate how many times as important the category of each row is compared with the category of each column. If the two are equally important, enter a **1.0**. If the row category is **MORE** important than the column category, enter the value (greater than one) comparing row to column. If the row category is **LESS** important than the column category, either directly enter the value (between zero and one) comparing row to column, or enter the value (greater than one) comparing column to row and then press **F2**. Pressing F2 automatically reverses the comparison by inverting the value. To change any comparison value, use the **↑** and **↓** keys to move to the desired field and enter the correct value.

To record comparison judgments between each pair of the three categories (Exhibit 9):

- The Monetary category is judged to be one and a half times as important as (or 50 percent more important than) Performance Measures, so type the value **1.5** in the first field and press **←**.
- The Strategic category is judged to be twice as important as Monetary. But, since you are asked for the reverse comparison:
 - Type the value **2**.
 - Press **F2** while still in the second field to reverse the order of the comparison and invert the value to 0.500.
 - Press **←**.

Recording Pairwise Comparisons between Categories			
Model: TUTORIAL			
	Monetary	PerfMeas	Strategc
Monetary	1.500	0.500	
PerfMeas		0.250	
Strategc			
For the overall decision, PerfMeas is how many times as IMPORTANT as Strategc? [Use 0.100 to 9.900]			
F1 for Help F2 to REVERSE Comparison ↓ ↑ for Next/Prior Pair PgDn to compute Weights Esc to Cancel			

Exhibit 9. Weighting Categories: Enter Pairwise Comparisons.

- The Strategic category is judged to be four times as important as Performance Measures, so in the third field:
 - Type the value 4.
 - Press **F2** to reverse the comparison and invert the value to 0.250.
 - Press **←** or **PgDn** to compute the category weights and the Inconsistency Ratio.

The category weights displayed in Exhibit 10 represent the relative importance that will be assigned to each category in determining the overall ratings of the alternatives. The weights are derived from the pairwise comparisons you just entered.

Note that the Inconsistency Ratio is less than 0.100, so there is no need to redo the comparisons. For an explanation of the Inconsistency Ratio, press the **F1** key now to display the help screen or refer to Section 2.

Recording Pairwise Comparisons between Categories			
Model: TUTORIAL			
	Monetary	PerfMeas	Strategc
Monetary		1.500	0.500
PerfMeas			0.250
Strategc			
	Monetary	PerfMeas	Strategc
Weights	0.263	0.159	0.578
Inconsistency Ratio	0.008	[Less than 0.100. Comparisons OK]	

Exhibit 10. Weighting Categories: Computed Weights and Inconsistency Ratio.

- Press **Esc** to display the Selection of Category for Pairwise Comparisons screen.

Once the categories have been compared with each other, you must weight the criteria within each category. The procedure for comparing criteria is the same as that for comparing categories. Comparisons must be entered for the criteria in each of the three categories listed in Exhibit 11. Here the procedure is illustrated in detail for the Performance Measures category.

Selection of Category for Pairwise Comparisons	
Model: TUTORIAL	
CATEGORY	CRITERIA LIST
Monetary	InitCost Revenue
PerfMeas	CycleTim Schedule Thruput Yield
Strategc	Flexity Quality Risk

Use ↓ ↑ to highlight Category and press:
 ← for Pairwise Comparisons F1 for Help
 Ctrl-End to View Shares Ctrl-Home to View Criteria Esc to Exit

Exhibit 11. Weighting Criteria: Select Category.

To compare the four evaluation criteria in the Performance Measures category:

- Press ↓ once to highlight PerfMeas, the abbreviation for Performance Measures.
- Press ← to display the Pairwise Comparisons between Criteria screen.

Press **F1** to see the help screen on comparing criteria. Since there are four Performance Measures criteria, a total of 6 (= 4 x(4-1) / 2) pairwise comparisons are needed. To correct an entry, use the ↑ and ↓ keys to move to the desired field and enter the correct value.

Enter the six comparison values as follows:

- Schedule is twice as important as CycleTim, so type the value **2** in the first field and then press **F2** to reverse the comparison. Press ←.
- CycleTim is twice as important as Thruput, so in the second field type the value **2** and press ←.
- CycleTim is three times as important as Yield, so in the third field type the value **3** and press ←.
- Schedule is twice as important as Thruput, so type **2** in the fourth field and press ←.
- Schedule is twice as important as Yield, so type **2** in the fifth field and press ←.
- Thruput is four times as important as Yield, so type **4** in the last field and press ←.

Exhibit 12 shows the screen after the numbers have all been entered and the weights and Inconsistency Ratio have been computed. The Inconsistency Ratio is greater than 0.100, so the comparison values should be reviewed.

There is a convenient method to force consistency by using the comparison values in the first row to derive the perfectly consistent values for the remaining comparisons. The method assumes the user has the most confidence in the first row comparisons. The consistent comparison value is the ratio of the first row value for the current column criterion to the first row value for the current row criterion. For example, the consistent value for comparing Schedule to Yield would be 6.000 (= 3.000/0.500), the value for comparing CycleTim to Yield divided by the value for comparing CycleTim to Schedule.

Recording Pairwise Comparisons between Criteria				
Model: TUTORIAL		Category: PerfMeas		
	CycleTim	Schedule	Thruput	Yield
CycleTim		0.500	2.000	3.000
Schedule			2.000	2.000
Thruput				4.000
Yield				
	CycleTim	Schedule	Thruput	Yield
Weights	0.290	0.378	0.228	0.104
Inconsistency Ratio	0.109	[Exceeds 0.100. Redo Comparisons]		
F1 for Help ← to Redo Esc to Exit				

Exhibit 12. Weighting Criteria: Pairwise Comparisons Cause Excessive Inconsistency

To edit the comparison values:

- Press ← to redo.
- Press ↓ four times to edit the field comparing Schedule to Yield where 2.000 is entered.
- Type **6** to replace the value 2.000 and press **PgDn** to recompute the weights and the Inconsistency Ratio. The Inconsistency Ratio is now much lower as shown in Exhibit 13.

Recording Pairwise Comparisons between Criteria				
Model: TUTORIAL		Category: PerfMeas		
	CycleTim	Schedule	Thruput	Yield
CycleTim		0.500	2.000	3.000
Schedule			2.000	6.000
Thruput				4.000
Yield				
	CycleTim	Schedule	Thruput	Yield
Weights	0.274	0.448	0.208	0.070
Inconsistency Ratio	0.036	[Less than 0.100. Comparisons OK]		
F1 for Help ← to Redo Esc to Exit				

Exhibit 13. Weighting Criteria: Revised Comparisons Improve Inconsistency Ratio.

Now press **Esc** to return to the Selection of Category for Pairwise Comparisons screen. At this screen (Exhibit 11), the Inconsistency Ratios for the categories already selected can be displayed. You can also review the share of the overall rating controlled by each category. Just hold down the **Ctrl** key and press **End** (Ctrl-End) to see the Inconsistency Ratios and shares. To restore the screen with the criteria lists, hold down the **Ctrl** key and press **Home** (Ctrl-Home).

To compare the importance of the two evaluation criteria in the Monetary category:

- Highlight the Monetary category.
- Press **↵**.
- Type **3** to indicate that InitCost is three times as important as Revenue.
- Press **↵** or **PgDn** to compute the weights and the Inconsistency Ratio.
- Press **Esc** to return to the Selection of Category screen.

To compare the importance of the three evaluation criteria in the Strategic category:

- Highlight the Strategic category.
- Press **↵**.
- Type the first two comparison values pressing **↵** after each one: **1.5** and **1**.
- For the third field type **1.5** then **F2** to reverse the comparison and invert the value to 0.667.
- Press **↵** or **PgDn** to compute the weights and the Inconsistency Ratio.
- Press **Esc** to return to the Selection of Category screen.
- Press **Esc** to return to the AutoMan Menu.

3.3 Rate Alternatives

The third step in AutoMan is to rate investment alternatives with respect to each criterion.

- Type **R** to select the Rate Alternatives option from the AutoMan Menu and display the Selection of Rating Criterion screen (Exhibit 14).

Selection of Rating Criterion	
Model: TUTORIAL	
CRITERION	CURRENT RATINGS
Existing	New
InitCost	
Revenue	
CycleTim	
Schedule	
Thruput	
Yield	
Flexity	
Quality	
Risk	

Use **↓** **↑** to highlight Criterion and press:

↵ for Pairwise Comparisons	D for Performance Data	F1 for Help
Ctrl-End to View Shares	Ctrl-Home to View Ratings	Esc to Exit

Exhibit 14. Rating Alternatives: Select Criterion.

At this step, each alternative is rated with respect to the nine criteria in the TUTORIAL model. Either of the two rating methods may be used: pairwise comparison or performance data. The pairwise comparison method is the same as that used in Step 2 for weighting categories and criteria. The performance data method requires actual data on the performance of each alternative with respect to the criterion. Press **F1** for help on deciding which rating method is appropriate to a given criterion.

Note that the performance data used for a criterion should be either directly or inversely proportional to the desirability of alternatives. Consequently, negative or zero values cannot be used for performance data. In such cases, the pairwise comparison method should be used for rating alternatives with respect to that criterion. Note also that all of the performance data for a given criterion must be entered in the same units. For example, use thousands of dollars valued at 1989 price levels. Similarly, if cash flows occur at different times, use discounting to convert all values for that criterion to the same time period.

Use **↓** and **↑** to highlight the criterion to be rated. You can also use the **PgDn** and **PgUp** keys to move to the bottom and top of the list of criteria.

To enter performance data for Revenue:

- Press **↓** once to highlight Revenue.
- Press **D** to enter performance data on the Revenue expected from the Existing and New alternatives.
- Type **900** for Existing and **1200** for New, pressing **←** after each (Exhibit 15). Ignore commas that appear as you begin to enter data. Once you press **←**, commas will automatically align based on the size of the number.
These two entries assume the Existing system results in \$900,000/year in Revenue and the New system results in \$1.2 million/year. The units in which the data are entered must be the same for all alternatives within the criterion being evaluated.
- Press **Y** for Yes at the question: "Are HIGHER Performance Values BETTER?"
Answering Yes indicates that you prefer more rather than less Revenue.

Rating Alternatives by Performance Data		
Model: TUTORIAL Criterion: Revenue		
ALTERNATIVE	PERFORMANCE	RATING
Existing	900	
New	1,200	
Are HIGHER Performance Values BETTER [Y/N]? Y		
F1 for Help PgDn to Compute Ratings Esc to Cancel		

Exhibit 15. Rating Alternatives: Enter Performance Data.

The Revenue ratings for the Existing and New systems will then appear to the right of the performance data (Exhibit 16). Note that New, with higher revenue, is given a proportionally higher rating for this criterion because higher values are better.

Rating Alternatives by Performance Data		
Model: TUTORIAL Criterion: Revenue		
ALTERNATIVE	PERFORMANCE	RATING
Existing	900	0.429
New	1,200	0.571
Are HIGHER Performance Values BETTER [Y/N]? Y		
F1 for Help	← to Redo	Esc to Exit

Exhibit 16. Rating Alternatives: Computed Ratings for Performance Data.

To enter performance data for Initial Cost (following the example for Revenue):

- Press **Esc** to return to the Selection of Rating Criterion screen depicted in Exhibit 14, which now shows the ratings just computed for Revenue.
- Press **↑** once to highlight InitCost, the abbreviation for the Initial Cost criterion.
- Press **D** to enter performance data on the initial costs of the Existing and New systems.
- Type **200** for Existing and **600** for New, pressing **←** after each.
The Existing system will require an initial outlay of \$200,000 in repair costs to continue in service, and the New system has an estimated initial cost of \$600,000. If the initial cost of the existing system were absolutely zero, the pairwise comparison method should be used to rate the alternatives with respect to initial cost.
- Type **N** for No when asked, "Are HIGHER Performance Values BETTER?" since higher costs are not better.
- Press **Esc** to return to the Selection of Rating Criterion screen (Exhibit 14).

The InitCost ratings for the Existing and New systems now appear, with a higher rating for the lower-cost Existing system.

Use the pairwise comparison method to rate alternatives with respect to evaluation criteria for which: (1) no objective performance data exists; (2) some alternatives have zero or negative performance values; or (3) performance is measured by the presence or absence of a feature. The method is similar to that for weighting criteria. Instead of judging the importance of criteria, however, you judge the performance of alternatives with respect to each criterion.

To judge the performance of alternatives with respect to Flexibility (since Flexibility is a criterion for which objective data are difficult to obtain):

- Highlight Flexity.
- Press **←** to display the Rating Alternatives by Pairwise Comparisons screen and press **F1** if you want to see the help screen on comparing alternatives.
- Type the value **3** then press **F2** to reverse the comparison, indicating that the New system will be three times as flexible as the Existing system.
Since our example is evaluating just two alternatives, you only need to make one comparison.
- Press **PgDn** to compute the Flexibility ratings (Exhibit 17).
Because there is no room for any inconsistency in judgment when comparing only two items, the Inconsistency Ratio is a perfect score of 0.000.
- Press **Esc** to return to the Selection of Rating Criterion screen.

Rating Alternatives by Pairwise Comparisons			
Model: TUTORIAL		Criterion: Flexity	
	Existing	New	
Existing		0.333	
New			
	Existing	New	
Ratings	0.250	0.750	
Inconsistency Ratio	0.000	[Less than 0.100. Comparisons OK]	
F1 for Help ← to Redo Esc to Exit			

Exhibit 17. Rating Alternatives: Computed Ratings for Pairwise Comparisons.

You must enter performance data or make pairwise comparisons for each of the criteria listed on this screen or the computed overall ratings will be incomplete and inaccurate. To complete the rating process for the remaining criteria enter the rest of the pairwise comparison data following the procedure illustrated for Flexity. Highlight the criterion, press **←** to select it, and enter the following data for each criterion in turn:

<u>CycleTim</u>	<u>Schedule</u>	<u>Thruput</u>	<u>Yield</u>	<u>Quality</u>	<u>Risk</u>
2 then F2	.75	3 then F2	2 then F2	2 then F2	2

Exhibit 18 shows the screen after all ratings have been completed.

- Press **Esc** to return to the AutoMan Menu.

Selection of Rating Criterion Model: TUTORIAL		
CURRENT RATINGS		
CRITERION	Existing	New
InitCost	0.750	0.250
Revenue	0.429	0.571
CycleTim	0.333	0.667
Schedule	0.429	0.571
Thruput	0.250	0.750
Yield	0.333	0.667
Flexity	0.250	0.750
Quality	0.333	0.667
Risk	0.667	0.333
Use ↓ ↑ to highlight Criterion and press: ← for Pairwise Comparisons D for Performance Data F1 for Help Ctrl-End to View Shares Ctrl-Home to View Ratings Esc to Exit		

Exhibit 18. Rating Alternatives: List of All Ratings.

3.4 Compute Overall Ratings

After the criteria have been weighted and the alternatives have been rated against all of the evaluation criteria, the Overall Ratings may be computed by AutoMan.

To compute the Overall Ratings:

- Press **C** at the AutoMan Menu.

To produce the Overall Rating for each alternative, AutoMan combines the weights derived from comparing the criteria with the ratings of the alternative with respect to each criterion. The Overall Rating equals the sum of the products of the criteria shares times the criteria ratings. The results appear in a bar chart as shown in Exhibit 19. The alternatives are ranked in the order of their overall ratings. For each alternative, the overall rating is displayed beside a horizontal bar proportional to the rating. Press **F1** to see the help screen explaining how the overall ratings are computed and describing the two types of printed reports available.

The Summary Report includes:

- Table 1. Ranking of Alternatives by Overall Rating
- Table 2. Model Structure, Weights, Shares, and Inconsistency Ratios
- Table 3. Ratings by Criterion and Overall Ratings of Alternatives

The Complete Report includes all tables of the Summary Report plus:

- Table 4. Pairwise Comparison Data for Weighting Categories and Criteria and for Rating Alternatives
- Table 5. Performance Data for Rating Alternatives

Computation of Overall Ratings			
Model: TUTORIAL			
RANK	ALTERNATIVE	RATING	
=>1	New	0.521	
2	Existing	0.480	
F1=Help S=Sensitivity Analysis P=Print Reports Esc=Exit			

Exhibit 19. Overall Ratings of the Alternatives.

The Complete Report for the completed TUTORIAL model is shown in Exhibit 20.

3.5 Conduct Sensitivity Analysis

If you have a graphical monitor, press **S** to select the Sensitivity Analysis option. Then move the light bar to any criterion and press **←** to display the sensitivity analysis plots for all the alternatives. The horizontal axis gives the percentage share of importance (weight) of the criterion being analyzed. The vertical axis gives the Overall Ratings of the alternatives. For reference, the current percentage share is marked with a vertical line. In this one graph you can see the Overall Ratings of every alternative for every possible percentage share assigned to the criterion of interest. The points where the lines intersect the left axis (the share is zero) indicate how alternatives would be rated if this criterion were totally ignored and all weight formerly attributed to it were redistributed proportionately to the remaining criteria. The points where the lines intersect the right axis (the share is 100 percent) indicate how alternatives would be rated if this were the only criterion that mattered and all other criteria were ignored. Breakeven points occur where the plots of two alternatives intersect. The rankings of the two alternatives reverse when the criterion share moves from one side of a breakeven point to the other. Press **P** to print the graph. Instructions for setting up your printer for graphical printing are in Section 2.5.

- Press **Esc** to return to the AutoMan Menu.

If you did not enter a complete set of data during the Tutorial, you may choose Select or Build a Model from the AutoMan Menu to return to the list of models and then select the model called EXAMPLE, which contains a complete data set for the Tutorial.

This concludes the Tutorial. If you want more practice with AutoMan, use the F5 option under Select or Build a Model to add alternatives to your TUTORIAL model and then redo the ratings following the illustrations in Section 3.3. You could also select either the SMALL or LARGE models and enter both weighting and rating data into them. Finally, you could press the F4 key to build a new model of your own using the Glossary of Evaluation Criteria.

When you are finished practicing with AutoMan, press **Q** at the AutoMan Menu to quit and safely close the files containing your models.

Exhibit 20. Complete Report for the TUTORIAL Model.

Model: TUTORIAL--Practice Model

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Table 1. Ranking of Alternatives by Overall Rating

RANK	ALTERNATIVE	RATING	
=>1	New	0.521	
2	Existing	0.480	

Exhibit 20. Complete Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model

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Table 2. Model Structure, Weights, Shares, and Inconsistency Ratios

CATEGORY	CRITERION	WEIGHT	SHARE	RATING INCONSISTENCY
MONETARY	InitCost	0.750	0.197	0.000
	Revenue	0.250	0.066	0.000
Weight = 0.263				
Inconsistency = 0.000				
PERFMEAS	CycleTim	0.274	0.044	0.000
	Schedule	0.448	0.071	0.000
	Thruput	0.208	0.033	0.000
	Yield	0.070	0.011	0.000
Weight = 0.159				
Inconsistency = 0.036				
STRATEGC	Flexity	0.375	0.217	0.000
	Quality	0.250	0.145	0.000
	Risk	0.375	0.217	0.000
Weight = 0.578				
Inconsistency = 0.000				

[Inconsistency of pairwise comparisons between categories = 0.008]

*Pairwise comparisons with inconsistency values > 0.1 should be redone.

Exhibit 20. Complete Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model

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Table 3. Ratings by Criterion and Overall Ratings of Alternatives

CATEGORY:		RATINGS	
CRITERION	Existing	New	
1: InitCost	0.750	0.250	
1: Revenue	0.429	0.571	
2: CycleTim	0.333	0.667	
2: Schedule	0.429	0.571	
2: Thruput	0.250	0.750	
2: Yield	0.333	0.667	
3: Flexity	0.250	0.750	
3: Quality	0.333	0.667	
3: Risk	0.667	0.333	
OVERALL RATING	0.480	0.521	

Exhibit 20. Complete Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model

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Table 4. Pairwise Comparison Data for Weighting Categories and Criteria
and for Rating Alternatives

Comparisons between Categories				
	Monetary	PerfMeas	Strategc	
Monetary		1.500	0.500	
PerfMeas			0.250	
Strategc				
Comparisons between Criteria within Category: Monetary				
	InitCost	Revenue		
InitCost		3.000		
Revenue				
Comparisons between Criteria within Category: PerfMeas				
	CycleTim	Schedule	Thruput	Yield
CycleTim		0.500	2.000	3.000
Schedule			2.000	6.000
Thruput				4.000
Yield				
Comparisons between Criteria within Category: Strategc				
	Flexity	Quality	Risk	
Flexity		1.500	1.000	
Quality			0.667	
Risk				
Comparisons between Alternatives rated by Criterion: InitCost				
[See Table 5 for Performance Data]				
Comparisons between Alternatives rated by Criterion: Revenue				
[See Table 5 for Performance Data]				
Comparisons between Alternatives rated by Criterion: CycleTim				
	Existing	New		
Existing		0.500		
New				
Comparisons between Alternatives rated by Criterion: Schedule				
	Existing	New		
Existing		0.750		
New				
Comparisons between Alternatives rated by Criterion: Thruput				
	Existing	New		
Existing		0.333		
New				

Exhibit 20. Complete Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model

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Table 4. Pairwise Comparison Data for Weighting Categories and Criteria
and for Rating Alternatives

		Comparisons between Alternatives rated by Criterion: Yield	
		Existing	New
Existing			
New		0.500	

		Comparisons between Alternatives rated by Criterion: Flexity	
		Existing	New
Existing			
New		0.333	

		Comparisons between Alternatives rated by Criterion: Quality	
		Existing	New
Existing			
New		0.500	

		Comparisons between Alternatives rated by Criterion: Risk	
		Existing	New
Existing			
New		2.000	

Exhibit 20. Complete Report for the TUTORIAL Model, cont.

Model: TUTORIAL--Practice Model

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Table 4. Pairwise Comparison Data for Weighting Categories and Criteria and for Rating Alternatives

Comparisons between Alternatives rated by Criterion: Yield		
	Existing	New
Existing		0.500
New		
Comparisons between Alternatives rated by Criterion: Flexity		
	Existing	New
Existing		0.333
New		
Comparisons between Alternatives rated by Criterion: Quality		
	Existing	New
Existing		0.500
New		
Comparisons between Alternatives rated by Criterion: Risk		
	Existing	New
Existing		2.000
New		

GLOSSARY OF EVALUATION CRITERIA

This glossary defines criteria for evaluating automated manufacturing investments that are used in the sample models of AutoMan. Other criteria may be relevant to manufacturing investment decisions, since such investments may have many diverse impacts. The particular mix of impacts pertinent to each organization, however, depends upon the intensity of automation and the organization's priorities. The intensity of automation affects the magnitude of an impact and whether the impact is significant enough to be included in the analysis. For example, at relatively low levels of automation, improved flexibility may not be possible because the rest of the factory will retain its specialized, dedicated equipment. In this environment, flexibility is unaffected and, therefore, not needed as a criterion.

An organization's priorities also determine whether an impact is important enough to warrant inclusion. Priorities vary by industry and competitive strategies. Even a large impact may not be relevant to an organization or a particular decision. For example, capacity utilization rates may significantly decrease with increased automation, but management may not wish to include this impact as a distinct evaluation criterion. A higher rate of capacity utilization may not be a desirable goal because it may lead to excess inventory; its effects may best be included as part of an inventory criterion.

The particular categories (groups of criteria) and criteria used in AutoMan's sample models are defined for illustrative purposes. The full name of each is given, followed by its abbreviated form to fit the eight character limit for labels in AutoMan. Categories are **bold-faced** and criteria are underlined. Some criteria, such as quality and risk, are often important to investment decisions, yet they involve complex issues that have not yet been resolved. The interpretation of such criteria may vary among organizations.

Refer to this glossary for criteria to consider when building a new model and revise and add to the definitions to meet the needs of your organization. In this way, a custom-made glossary can be developed to promote consistency in meaning among multiple users within the same organization.

Monetary Category (Monetary)

Evaluation criteria that can either be directly measured in dollars or derived from dollar-denominated data (e.g., financial ratios). Includes traditional measures of financial worth, all of which are derived from essentially the same data. Be aware of possible double counting if several of these measures are included in a model. This category may be further subdivided into a **Benefits Category (Benefit)**, composed of criteria for which higher values are better, and a **Costs Category (Cost)**, composed of criteria for which lower values are better.

Benefit-to-Cost Ratio (BCR): Monetary benefits divided by costs, where both are discounted to a present value or equivalent uniform annual value (American Society for Testing and Materials, 1989).

Initial Cost (InitCost): The sum of design, purchase, installation, financing, and transition costs necessary to make new automated manufacturing equipment ready for use. For existing equipment, any immediate repair or replacement costs necessary to keep it in operation.

Internal Rate of Return (IRR): The compound rate of interest that equates the stream of dollar benefits or savings to dollar costs over some defined study period. When the return is measured solely on the original investment (which implicitly suggests the same return on reinvestments as on the original investment), this measure is known as the unadjusted internal rate of return. When a combined return on the original investment and reinvested earnings is measured, it is known as the adjusted internal rate of return (American Society for Testing and Materials, 1989, pp. 1114, 1119).

Inventory Cost (Inventory): The sum of (1) the cost of ordering purchased parts for raw materials inventory, or the cost of machine setup for finished goods inventory, plus (2) inventory carrying costs. If there is a stockout problem, other factors to be considered are stockout cost per unit, demand during lead time, and the economic ordering quantity (Jordan, 1987, pp. 185-190). With automated manufacturing, combined operations, together with reductions in non-productive times, may reduce work-in-process inventory levels. Finished goods inventories may also be reduced as a result of smaller lot sizes and shorter cycle times.

Life-Cycle Cost (LCC): The sum, over some defined study period, of costs of initial investment (less resale value), replacements, operations (including energy use), and maintenance and repair of an investment. This measure is expressed in present or annual value terms (American Society for Testing and Materials, 1989).

Net Benefits (NB): The difference between the monetary benefits and costs--where both are discounted to present or annual value dollars (American Society for Testing and Materials, 1989).

Payback Period (Payback): The time required for the cumulative benefits from an investment to pay back the investment cost and other accrued costs. When the time value of money is not considered, this measure is known as the simple payback period; when the time value of money is considered, it is known as the discounted payback period (American Society for Testing and Materials, 1989).

Project Cash Flow (CashFlow): The stream of monetary values--costs and benefits--resulting from a project investment (American Society for Testing and Materials, 1989).

Revenue (Revenue): Total dollar sales volume per time period.

Rework Losses (Rework): The cost of correcting defective work. Rework losses are also the cost of work performed to correct service-revealed difficulties when the work is performed before the part is delivered to the customer (Jordan, 1987, p. 130).

Scrap Losses (Scrap): The cost of any component which, due to defective work on the part of the machine operator, damage in handling, or other causes, makes the part unfit for use in the end product. Included also is the cost of parts that are made to predetermined specifications but that are scrapped due to service-revealed problems that cannot be corrected through rework (Jordan, 1987, p. 130).

Performance Measures Category (PerfMeas)

Evaluation criteria that can be measured, but not easily converted to dollars. Includes non-monetary measures of business and plant effectiveness in relation to the goals and objectives developed in the strategic planning process (Computer Aided Manufacturing-International, Inc., 1988, p. 159).

Capacity Utilization Rate (CapUse): The ratio of actual output to full-capacity output (Bannock et al., 1972, p. 55).

Customer Lead Time (CustLead): The final phase in the production cycle is the delivery of the product to the customer. Customer Lead Time is the amount of time between the receipt of an order and actual product delivery.

Cycle Time (CycleTim): The time between arrival at the factory of material for a product and shipping of the product (CAM-I, 1988, p. 239). Cycle time is dependent upon: (1) the number of machines through which a part is routed, (2) machine setup time, (3) batch size, (4) operation time (machine time, and workpart and tool handling times), and (5) non-operation time (transportation, delays, and inspections) (Salomon and Biegel, 1984, p. 89). Increased automation may affect all five of these components of cycle time.

Productivity (Prodtiv): The comparison of the output of a production process or an enterprise with the corresponding inputs (e.g., labor, materials, capital) required to generate that output. Productivity measures are formulated as a ratio of output to one or more of the inputs (Weber and Lippiatt, 1983, p. 1).

Schedule Attainment (Schedule): The percentage of acceptable output to total scheduled output at the scheduled due date. Automation may improve schedule attainment by increasing the level of operational control and by allowing more accurate production forecasts derived from an integrated data base.

Setup Time (Setup): The time required to prepare a machine or work center for a manufacturing process (CAM-I, 1988, p. 244). Automation permits shorter setup times because any process that has been set up once, can be set up quickly again by reprogramming, compared with the retooling required in traditional manufacturing (Rhea, 1984, p. 50).

Throughput (Thruput): The amount of raw material processed within a given time period (Random House, Inc., 1973, p. 1370). Since automation is designed to improve material flow, it is likely to improve throughput of individual processes. When measuring the impact of automation on product throughput, however, total factory throughput is most important. An improvement in the modified area is offset somewhat by bottlenecks in others.

Vendor Lead Time (VendLead): The first phase in the production cycle is the request for and delivery of parts. Vendor Lead Time is the amount of time between the request for delivery of parts and their arrival (CAM-I, 1988, p. 241).

Yield (Yield): Actual output, expressed as the percentage of what is theoretically possible.

Strategic Category (Strategic)

Evaluation criteria that cannot easily be measured. Includes issues often associated with goals and objectives outlined in the long-term or strategic planning process.

Flexibility (Flexity): The ability to respond effectively to changing circumstances (Zelenovic, 1982). Flexibility is a strategy used to deal with uncertainties both in the market and in the manufacturing process. Gerwin has developed a useful taxonomy of flexibility consisting of six sets of uncertainties, strategic objectives, and corresponding flexibilities. The first four relate to uncertainties in the market; the last two to uncertainties in the manufacturing process (Gerwin, 1989, pp. 79-82; Gerwin and Tarondeau, 1989, pp. 171-172).

Mix Flexibility (MixFlex): Uncertainty as to which products will be bought by customers leads to mix flexibility, or the ability of a manufacturing process to produce a wide variety of products without resorting to time consuming setups and material handling delays. Mix flexibility is associated with the strategic objective of product diversity.

Changeover Flexibility (ChngFlex): Uncertainty as to the length of product life cycles creates a need for changeover flexibility, or the ability of a process to deal with additions to and deletions from the mix of products over time. Changeover flexibility is needed to meet the strategic objective of product innovation.

Modification Flexibility (ModFlex): Uncertainty as to which particular product attributes customers want creates a need for modification flexibility, or the ability to make minor design changes in a given product. Modification flexibility meets the strategic objective of being responsive to customers.

Volume Flexibility (VolFlex): Uncertainty about the amount of aggregate product demand leads to volume flexibility, or the ability to change the aggregate amount of production. Volume flexibility is related to the strategic objective of building or maintaining market share.

Routing Flexibility (RoutFlex): Uncertainty regarding machine downtime gives rise to routing flexibility, or the ability to change the machining sequence for a part when breakdowns or renovations occur. Routing flexibility is needed to satisfy the strategic objective of meeting customers' due dates.

Material Flexibility (MatlFlex): Uncertainty as to whether inputs to a manufacturing process meet standards leads to material flexibility, or the ability to handle unexpected changes in the composition and dimensions of parts. Material flexibility is associated with the strategic objective of product quality.

Manufacturing Quality (Quality): The ability of a manufacturing process to produce acceptable output without defects being introduced during the production process. A goal of defect prevention is to build the product correctly the first time. Automated manufacturing improves manufacturing quality by using in-line, real-time, automated inspection, which flags potential problems before defective products emerge. The integrated database helps errors in the software that controls manufacturing to be detected and removed after the first run. Moreover, reduced direct labor content leads to fewer operator errors (CAM-I, 1988, pp. 82, 184).

Risk (Risk): The probability that an investment will result in an economic outcome different from what is desired or what is expected. This is properly called risk exposure. Risk attitude is the willingness of decision makers to undertake investments of uncertain outcome (Marshall, 1988, pp. ix-x). Risk attitude can be incorporated in the pairwise comparisons with the other criteria in the model. Four types of risk exposure criteria related to automated manufacturing investments follow (CAM-I, 1988, pp. 185-186).

Economic Risk (EconRisk): The probability that using a candidate technology will not achieve the projected economic benefits because of legislative trends, inflation rate changes, interest rate changes, competition from other companies, or time and resource constraints.

Technological Risk (TechRisk): The probability that a technology will fail to achieve the desired manufacturing benefits. Higher risks are associated with both older technologies (due to increased probability of obsolescence) and leading edge applications. Technological risk factors associated with leading edge applications include hardware failure, software failure, lack of vendor support, and communication facility failures.

Implementation Risk (ImplRisk): The probability that human resource factors will prevent successful implementation of the candidate technology. These factors include employee attitudes and skills, personnel education and training/retraining, employee reward system, organizational impact, and compatibility of the new technology with current operating procedures.

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NIST-114A (REV. 3-90)		U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY		1. PUBLICATION OR REPORT NUMBER NISTIR 4543
BIBLIOGRAPHIC DATA SHEET				2. PERFORMING ORGANIZATION REPORT NUMBER
				3. PUBLICATION DATE MARCH 1991
4. TITLE AND SUBTITLE AutoMan 2.0 Decision Support Software for Automated Manufacturing Investments: User Manual				
5. AUTHOR(S) Weber, Stephen F.; Lippiatt, Barbara C.; Johnson, Katherine S.				
6. PERFORMING ORGANIZATION (IF JOINT OR OTHER THAN NIST, SEE INSTRUCTIONS) U.S. DEPARTMENT OF COMMERCE NATIONAL INSTITUTE OF STANDARDS AND TECHNOLOGY GAITHERSBURG, MD 20899			7. CONTRACT/GRANT NUMBER	
			8. TYPE OF REPORT AND PERIOD COVERED final	
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (STREET, CITY, STATE, ZIP) Office of the Assistant Secretary of the Navy Manufacturing Technology Program Washington, D.C.				
10. SUPPLEMENTARY NOTES				
11. ABSTRACT (A 200-WORD OR LESS FACTUAL SUMMARY OF MOST SIGNIFICANT INFORMATION. IF DOCUMENT INCLUDES A SIGNIFICANT BIBLIOGRAPHY OR LITERATURE SURVEY, MENTION IT HERE.) This manual documents AutoMan, a microcomputer program designed to support multi-criteria decisions about automated manufacturing investments. The program permits users to combine quantitative and qualitative criteria in evaluating investment alternatives. Quantitative criteria could include such traditional financial measures as Life-Cycle Cost and Net Present Value as well as such engineering performance measures as throughput and setup time. Qualitative criteria could include flexibility and product quality. First, the user specifies the evaluation criteria and the investment alternatives to be evaluated. Second, the user makes pairwise comparisons between criteria to establish their weights. Third, the user rates each investment alternative with respect to the criteria. The pairwise comparison process helps the user rate the qualitative criteria, while measured performance data, such as cost, setup time, or throughput, can be entered for quantitative criteria. AutoMan combines ratings with criteria weights into an overall rating for each investment alternative and then ranks alternatives. Finally, graphical sensitivity analysis can be conducted to visualize the overall ratings of every alternative for every possible weight that could be assigned to any criterion. AutoMan comes with sample decision models and a manual that includes a detailed tutorial, a glossary of evaluation criteria, a bibliography, and an index.				
12. KEY WORDS (6 TO 12 ENTRIES; ALPHABETICAL ORDER; CAPITALIZE ONLY PROPER NAMES; AND SEPARATE KEY WORDS BY SEMICOLONS) Analytic hierarchy process; automated manufacturing; automation; decision support software; economic evaluation; microcomputer software; multi-criteria decisions; performance measures; qualitative data; sensitivity analysis.				
13. AVAILABILITY ☒ UNLIMITED ☐ FOR OFFICIAL DISTRIBUTION. DO NOT RELEASE TO NATIONAL TECHNICAL INFORMATION SERVICE (NTIS). ☐ ORDER FROM SUPERINTENDENT OF DOCUMENTS, U.S. GOVERNMENT PRINTING OFFICE, WASHINGTON, DC 20402. ☒ ORDER FROM NATIONAL TECHNICAL INFORMATION SERVICE (NTIS), SPRINGFIELD, VA 22161.			14. NUMBER OF PRINTED PAGES 47	
			15. PRICE A03	

